FINDINGS

OF THE

Moon→Mars SCIENCE LINKAGES SCIENCE STEERING GROUP (MMSL-SSG)

Chip Shearer and David Beaty (co-chairs), Ariel Anbar, Bruce Banerdt, Don Bogard, Bruce A. Campbell, Michael Duke, Lisa Gaddis, Brad Jolliff, Rachel C. F. Lentz, David McKay, Greg Neumann, Dimitri Papanastassiou, Roger Phillips, Jeff Plescia, Mini Wadhwa

Jan 24, 2005

Note: This is the presentation version of the white paper "Final Report of the Mars-Moon Science Linkages Science Steering Group (July, 2004)". If there are any discrepancies between the two documents, the white paper should be judged to be superior.

Outline of Presentation

- Introduction.
  - MMSL-SSG Charter.
  - Membership.
  - Assumptions of the Study.
- The Moon as a Unique Vantage Point for SS Exploration.
- Examples of Potential Linkages.
  - Linkages between Moon and Mars.
  - Linkages between science investigations and technology development.
- Setting Priorities.

MMSL SSG Charter

The Moon→Mars Science Steering Group was chartered on behalf of MEPAG to complete the following:

1. Develop an analysis of the potential ways in which the scientific objectives for the exploration of Mars can be advanced through any of the following activities:
   a) Scientific investigations on the Moon
   b) Engineering demonstrations on the Moon (including demos of technically challenging scientific activities)
      - Demonstrations of instrument, tool, and spacecraft operations.
2. Develop an assessment of the priority of the possibilities outlined above.

Moon→Mars SSG Membership

Science Members		
Ariel Anbar	Univ. of Rochester	geochem of early earth, A/B
Bruce Banerdt	JPL	geophysics
Don Bogard	JSC	Geochronology
Bruce A. Campbell	Smithsonian CEPS	geophysics/SHARAD
Michael Duke	Colorado School of Mines	Resources
Lisa Gaddis	USGS, Flagstaff	remote sensing, MER
Brad Jolliff	Wash. U.	petrology/geochemistry
Rachel C. F. Lentz	U Tennessee	petrology/geochemistry
David McKay	JSC	geology/astrobiology
Greg Neumann	GSFC/MIT	Geophysics/geodesy
Dimitri Papanastassiou	JPL	geochem (isotopes)
Roger Phillips	Wash. U.	geophysics, geology
Jeff Plescia	JHU APL	Mars geology
Charles Shearer	U. New Mexico	petrology/geochemistry
Mini Wadhwa	Field Museum, Chicago	geochemistry, meteorites
Program Representatives		
David Beaty	MPO--JPL	Program manager
Jim Garvin	NASA HQ	Program Science

Bold denotes team leader

MMSSG subcommittees

- **Mars Priority sub-team**. Bruce Banerdt, Mini Wadhwa, Rachel Lentz.
- **Moon Priority sub-team**. Don Bogard, Dimitri Papanastassiou, Bruce Campbell
- **Overall Priority sub-team**. Roger Phillips--leader

Assumptions for this Study

1. Assume scientific priorities for the exploration of Mars are described in the MEPAG Goals document (http://mepag.jpl.nasa.gov/reports/MEPAG_goals-3-15-04-FINAL.doc).

2. Assume a Lunar Reconnaissance Orbiter (LRO) mission to the Moon in 2008, a robotic landed mission by 2010, and a TBD schedule of robotic lunar missions until a first human return to the lunar surface in 2020.

3. This SSG is asked to focus its effort on martian and lunar surface science, rather than orbital science.

Assumptions for this Study

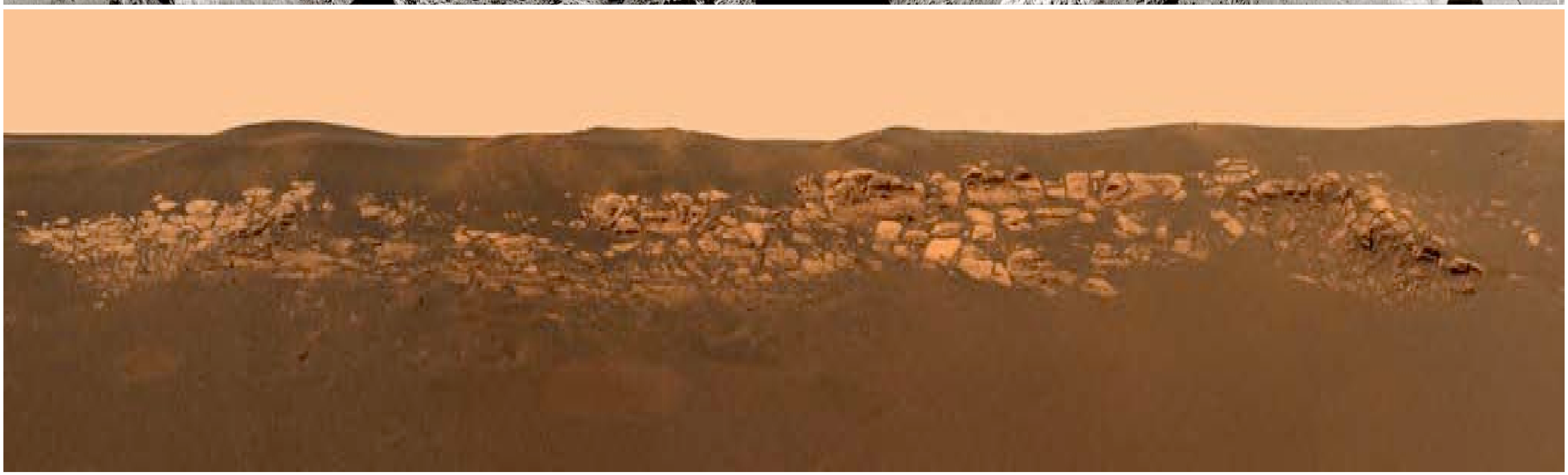
Lunar science objectives

The most recent consensus-based description of lunar science goals, objectives, and investigations was developed by the Lunar Exploration Science Working Group (LExSWG). This information is available in the following reports:

1. A Planetary Science Strategy for the Moon, Lunar Exploration Science Working Group, July 1992, JSC document JSC-25920, 26 pp.
2. Lunar Surface Exploration Strategy, Lunar Exploration Science Working Group (LExSWG), Final Report, February, 1995, 50 pp.

   Both available at: http://www.lpi.usra.edu/lunar_return/

Are there scientific and engineering linkages between Moon and Mars?



The Moon as a Unique Vantage Point for Solar System Exploration

FINDING: The Moon offers a unique vantage point for certain aspects of Solar System exploration

- Cornerstone for Early Planetary Processes
- Volatile Record and Reservoirs
- Testbed for Scientific Exploration of the Solar System
- Astrobiology

Cornerstone for Early Planetary Processes

- Preserves the remnants of one style of planetary differentiation: Magma Ocean.
- Illustrates a style of early planetary asymmetry that is related to early differentiation processes.
- Illustrates a pathway of planetary evolution that is related to a style of planetary accretion and differentiation.
- Illustrates the full crustal formational and magmatic history of a cooling planetary body.
- Recorded and preserved the early impact environment of the inner solar system.
- Interactions between a planetary surface and space are preserved in the lunar regolith.

The Moon as a Unique Vantage Point for Solar System Exploration

Volatile Record and Reservoirs

- Moon is an planetary end-member for volatile abundance.
- Clearer view of three primary sources of volatiles:
  - Endogenous
    - Volcanism, volcanic degassing
  - Exogenous
    - Solar wind and galactic cosmic rays
    - Impacts of comets and asteroids
- Lunar surface contains all three, although endogenous volatiles are in very low abundance. The lunar surface is unprotected from space exposure.
- Lunar surface records solar wind, galactic cosmic ray history. Polar cold traps may record the more volatile species from volcanic eruptions and impacts.
- Martian surface contains abundant endogenous volatiles and is protected by atmosphere and potentially larger ancient magnetic field.
- Volatiles on Mars, especially water, present at poles, in megaregolith, in atmosphere, bound in minerals, etc.

The Moon as a Unique Vantage Point for Solar System Exploration

Testbed for Scientific Exploration of the Solar System

- The Moon has a number of unique testbed attributes:
  - _ Close proximity to Earth.
  - _ Hostile environment.
    - *Atmosphere*
    - *Temperature*
    - *Low volatile content*
    - *Dust*
  - Reduced gravity levels.
  - Low seismicity.
  - Planetary-scale sterile environment.

The Moon as a Unique Vantage Point for Solar System Exploration

Astrobiology

●The Moon preserves unique historical information about events and processes that affected the habitability of the entire inner Solar System, a record obscured on Earth and Mars.

- *Impact chronology (esp. first billion years)*
- *Composition of impactors, IDPs flux, etc.*
- *Delivery of exogenous volatiles and organics*
- *Nearby supernovae and Gamma Ray Burst (GRB) events*
- *Solar activity (solar wind; flares)*

●The Moon provides a uniquely accessible planetary-scale sterile environment useful for assessing engineering goals of astrobiological importance, especially for life detection and planetary protection.

- *Control experiments for life-detection technologies (extinct and extant)*
- *Quantify "forward contamination" by robotic and human explorers*

Moon→Mars Linkages

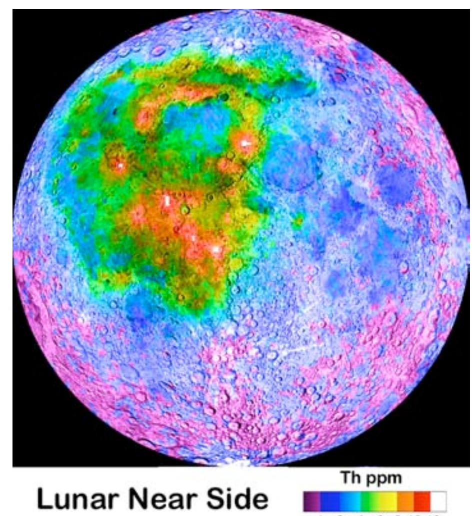
<u>FINDING</u>: We have identified three categories of linkages between possible lunar exploration activities and a future benefit to martian science. These are organized as:

- **<u>Category A</u>. Investigations related to processes of terrestrial planet formation and evolution**
- **<u>Category B</u>. Human-related resource issues**
- **<u>Category C</u>. Demonstrations of scientific methods and capabilities**

Category	# of Linkages Identified
A	10
B	3
C	7
TOTAL	**20**

A. <u>Investigations</u> related to the processes of terrestrial planet formation and evolution.

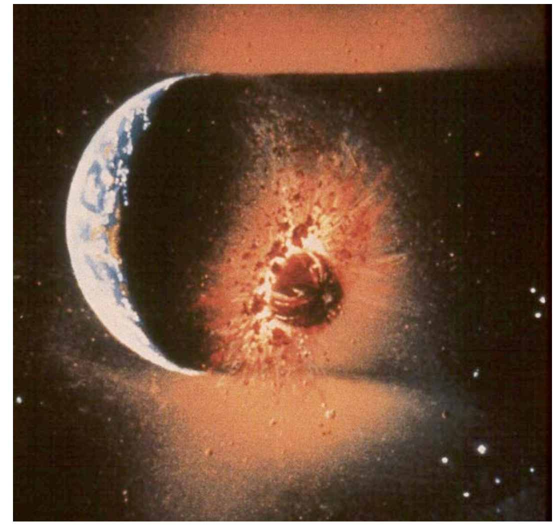
- **Early planetary evolution and planetary structure.**
  - ***A1. Interior Planetary Structure.***
  - ***A2. Early Planetary Differentiation.***
  - ***A3. Thermal and Magmatic Evolution.***
  - ***A4. Planetary Asymmetry.***

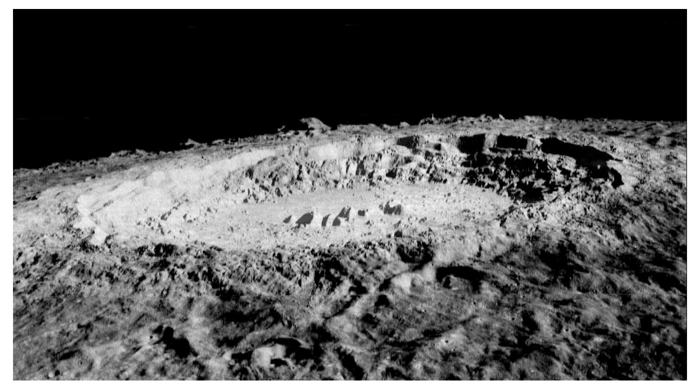


Lunar Near Side

A. Investigations related to the processes of terrestrial planet formation and evolution.

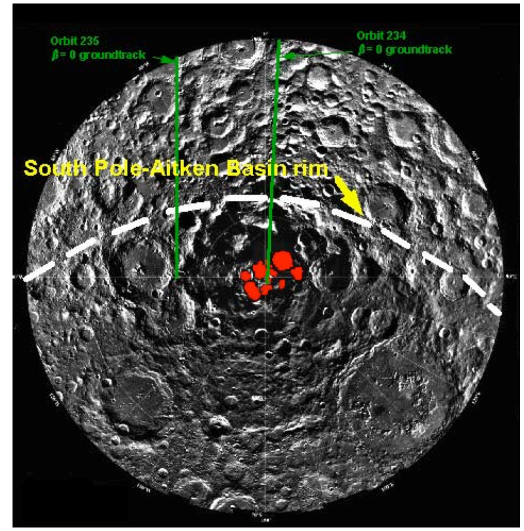
- **Early planetary surfaces.**
  - ***A5. Impactor Flux vs. Time.***
  - ***A6. Regolith History.***
  - ***A10. Interpreting Geologic Environments***

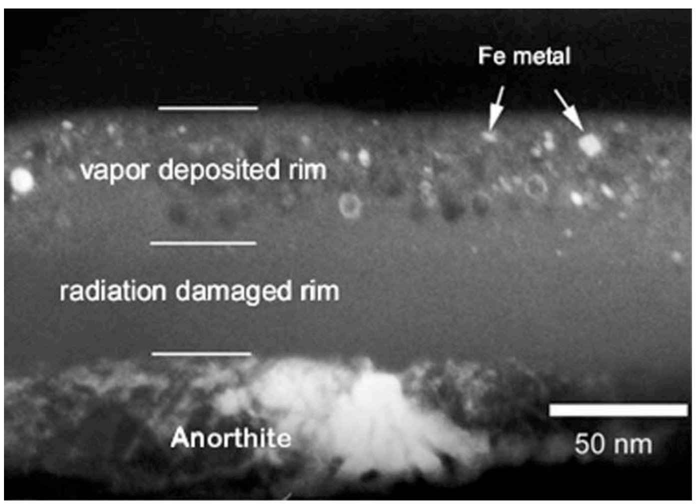


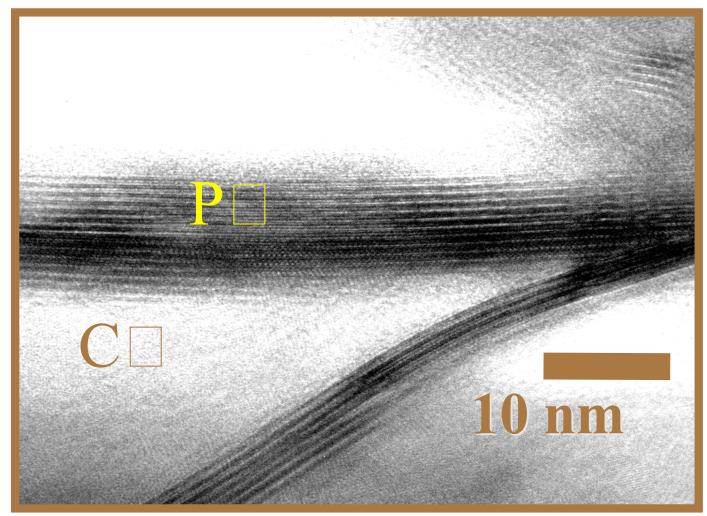


A. <u>**Investigations**</u> related to the processes of terrestrial planet formation and evolution.

- Record of volatile evolution and behavior.
  - A7. Energetic Particle History.
  - A8. Endogenous Volatiles.
  - A9. Exogenous Volatiles.







A1. Interior Planetary Structure

What is the Linkage?

- Understanding the structure of planetary interiors is fundamental for understanding the origin and differentiation of a planet, dynamical processes, surface evolution, tectonics, magmatism, magnetic field, evaluating resources..

Relevance to Lunar Science

- Provide constraints for the bulk composition of the Moon, its origin, and the manner in which it differentiated.
- Characterize crust, mantle, core structural domains, to anchor our understanding of lunar asymmetry, mantle dynamics, magnetic field and current thermal state.

Relevance to Mars Science

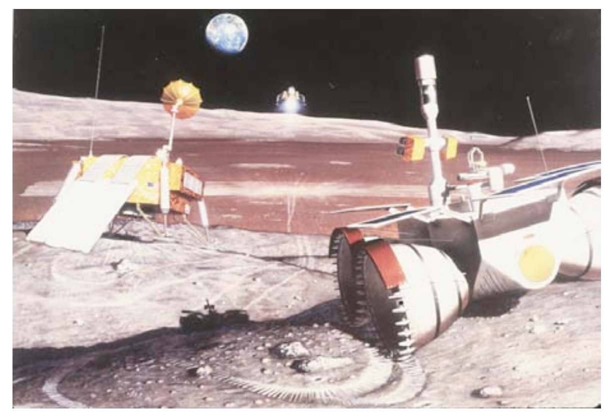
- Place constraints on the mechanism of martian differentiation and early dynamical processes of the martian interior.
- Characterize the current structure and dynamics of the martian interior.
- Determine the origin and history of the magnetic field.

Possible Lunar Measurements

- Moon-wide seismic array.
- Far side gravity field measurements.
- Detailed topography measurements
- Ranging Transponders on Surface

B. Evaluate lunar resources to be used to support exploration activities on the Moon and beyond.

- Investigations
  - *B1. Water as a Resource*
  - *B2. In-situ fuel sources*
  - *B3. Exploration and Processing of Planetary Materials*



B1. Water as a Resource

What is the Linkage?

- Water is critical to life support for human missions to both bodies.
- Moon and Mars may contain accessible water in various forms.
- Exploration questions are similar: What is form, concentration, extraction processes.

Relevance to Lunar Exploration

- Determine locations and physical/ chemical form of lunar water
- Utilize water-rich layers as tracers for lunar regolith processes.
- Utilize lunar propellant to support Moon-space transportation.

Relevance to Mars Exploration

- Demonstrate use of in situ derived water for life support activities.
- Develop/demonstrate exploration approaches to determining chemical and physical properties of volatile deposits.

Possible Lunar Measurements

- Characterize of hydrogen in lunar polar regions – form, concentration, extractability.
- Develop efficient technologies for excavating regolith and extracting H_2/H_2O.
- Develop technologies for purification and storage.

C. Demonstrations at the Moon to gain experience, mitigate risk, improve performance, confirm capability and cost reduction technologies.

Investigations

- *C1. In-situ Sample Selection and Analysis*
- *C2. Communication and Ranging Systems*
- *C3. Drilling Technologies*
- *C4. Seismic Technologies/Studies*
- *C5. Life Detection & Planetary Protection*
- *C6. ISRU Technology Demonstrations*
- *C7. Sample Return*

C6. ISRU Technology Demonstrations

What is the Linkage?

- Use of in-situ resources for support of human and robotic missions.
- Although there is significant differences in the surface environments that could lead to different technological approaches, at a sub-system level, there are many commonalities.
- Many processes are affected by operations at reduced gravity levels (two phase flows, scaling laws for material handling).
- Demonstrating reliability/stability/longevity of power systems and sensors in a harsh planetary environment

Relevance to Lunar Science

- Excavation technologies (and knowledge of regolith physical properties) are required for any process that extracts useful materials from the regolith (e.g. radiation shielding, oxygen production)
- Efficient thermal extraction processes needed to demonstrate feasibility of extracting minor volatile constituents from regolith (H, C, N)
- Materials handling (both solids and gases) demonstrations are needed to understand factors that will allow scale-up from robotic to human scale missions.

Relevance to Mars Science

- Excavation technologies are required for any process that extracts useful materials from the regolith (e.g. radiation shielding, water extraction from hydrated minerals) on Mars.
- Demonstration of ISRU capability on the Moon will increase the likelihood that such approaches will be used on Mars.
- Long-term testing of systems to establish reliability and maintainability is essential because Mars applications will be difficult to repair if they fail.

Possible Lunar Measurements

• Practical small-scale excavators.
• Regolith thermal extraction of volatiles and gas separation and purification technologies.
• Hydrogen or carbon reduction processing of lunar regolith to produce oxygen.
• Demonstrations of practical use for lunar exploration, such as charging a fuel cell on a rover for long-range exploration.

Moon→Mars Priorities

FINDING: We have found significant differences in the **relative** priority of the identified Moon→Mars linkages.

1. The priority of Moon→Mars linkages was assessed:
   a) From the perspective of Mars alone
   b) From the perspective of the Moon alone

Note: Assessing priority in an absolute sense requires that factors beyond the scope of this study be considered.

Priority of Identified Lunar Investigations
to Mars Science

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP 1:

A5: Impactor Flux vs. Time

A9: Exogenous Volatiles

PRIORITY GROUP 2:

A3: Thermal and Magmatic Evolution

A10: Interpreting Geologic Environments

A6: Regolith History

A8: Endogenous Volatiles

PRIORITY GROUP 3:

A1: Interior Planetary Structure

A4: Planetary Asymmetry

A2: Early Planetary Differentiation

A7: Energetic Particle History

LOWER

Prioritization Criteria:

- The intrinsic scientific value of each theme for advancing our understanding of Mars if the investigation was first carried out on the Moon.
- Degree of criticality of the possible lunar activity to one or more future Mars missions (or surface measurement activities)
- Degree of alignment with MEPAG's priority system for Mars exploration

Note: Differences in priority within priority groups are not judged to be significant.

Priority of Identified Lunar Investigations
to Lunar Science

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP 1:

A1. Interior Planetary Structure

A2. Early Planetary Differentiation

A5. Impactor Flux vs. Time

PRIORITY GROUP 2:

A3. Thermal & Magmatic Evolution

A4. Planetary Asymmetry

A10. Interpreting Geologic Environments

A9. Exogeneous Volatiles

A6. Regolith History

PRIORITY GROUP 3:

A7. Energetic Particle History

A8. Endogenic Volatiles

LOWER

Prioritization Criteria:

- Intrinsic scientific value (for the Moon).
- Degree to which identified investigations are likely to make major contributions to advancing knowledge about the important science questions.
- Feasibility within the emerging strategy for precursor robotic lunar missions in support of human exploration.

Note: Differences in priority within priority groups are not judged to be significant.

Resource and Demo. Priorities

Test crucial instrument or strategy, or establish test bed under the proviso that (*i*) Activity cannot be done satisfactorily on Earth, or (*ii*) Moon provides a unique (or vastly superior) martian analog than does the Earth.

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP #1:

C1: In-situ sample selection and analysis
C7: Sample Return
C3: Drilling technologies

PRIORITY GROUP #2:

C4: Seismic technologies/Studies
B1: Water as a Resource
B2: In-situ fuel resources
C5: Assess Bio-Organic Contamination

PRIORITY GROUP #3:

C6: ISRU Technology Demonstrations
C2: Communication and ranging systems
B3: Other resource issues

LOWER

Prioritization Criteria:

1. If successfully carried out at the Moon, the value to our ability to correctly plan and successfully implement the future Mars exploration program.
2. Timing: Importance that these measurements/demonstrations be carried out by the lunar robotic program prior to 2020.
3. Cost: General affordability of these measurements/ demonstrations.
4. Technology readiness: Our technical ability to carry out these measurements/ demonstrations within the time frame specified in #2 above.